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Computer-guided implant surgery: A critical review of treatment concepts

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ABSTRACT

Objectives: The aim of the present study was to conduct a critical literature review about the treatment concepts of computer-guided surgery in implantology to highlight indication about major advantages and complications of the technique.

Materials, methods and results: The literature review was based on Medline database from 2007 to 2012 using the key words "computer-guided implant surgery" for studies written in English. For inclusion, publications had to meet pre-established criteria. Three reviewers independently selected 42 full text articles. The publications included: 18 clinical evaluations, 10 technical notes, 8 clinical reports, and 6 reviews.

Conclusion: The scientific evidence available suggests that guided placement has at least as good implant survival as conventional protocols. However several unexpected procedure-linked adverse events during guided implant placement indicate that the clinical demands on the surgeon were no less than those during conventional placement.

Contents

☆ AsianAOMS: Asian Association of Oral and Maxillofacial Surgeons; ASOMP: Asian Society of Oral and Maxillofacial Pathology; JSOP: Japanese Society of Oral Pathology; JSOMS: Japanese Society of Oral and Maxillofacial Surgeons; JSOM: Japanese Society of Oral Medicine; JAMI: Japanese Academy of Maxillofacial Implants.

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1. Introduction

Advances in computed tomography (CT) technology, which allow better visualisation of bone morphology than standard two-dimensional (2D) radiographs, along with the development of planning software, have improved the predictability of implant treatment [1]. With these new approaches, implant placement can be based on computerised three-dimensional (3D) plans, making it less dependent on surgeon experience, knowledge of the prosthetic treatment plan, and the specific anatomy of a given patient. Moreover, a fixed prosthesis can be prefabricated in the laboratory using a cast based on a surgical guide and loading can start immediately after implant insertion [2].

Considering these concepts, we reviewed the literature on the treatment concepts of computer-guided surgery (CAS) in implantology, to highlight the purposes, indications, fabrication protocols, and complications of each procedure.

2. Background

Implant planning is currently based on sophisticated diagnostic imaging. The exact positioning of the fixtures is one of the more important goals of the surgical phase [3]. Modern surgery is based on improved diagnostic technologies that give the surgeon more precise information on patient anatomy, allowing the surgeon to interact dynamically with a 3D reconstruction and to simulate the result of the surgery to evaluate different surgical approaches before the actual surgical treatment. Then, the virtual treatment plan can be transferred to clinical practice through the use of surgical guides, which allow fixture insertion the ideal position as predetermined virtually.

One main outcome of computer-assisted surgery is the possibility of inserting implants in a more accurate manner in limited bony volumes using a precise guide and these modern techniques allow less invasive approaches like flapless surgery and simplify the prosthetic procedures involved with immediate-loading protocols. In practice, the increasing interest among clinicians in flapless procedures allowing immediate loading has led to the development of software that can use CT data to produce an elaborate, virtual 3D model for simulating the implant surgery and prosthetic phase.

The computer-assisted surgery protocol involves three successive phases: the planning, the surgical phases, the prosthetic phase. The accurate planning of every step in each phase has a strong influence on the subsequent stages and therefore on the precision of the final result.

3. Materials and methods and results

3.1. Description of the method

To ensure a systematic approach, this literature review comprised the following steps: formulating a strategy for the electronic database search; literature search/retrieval of publications; data extraction; and the evaluation of relevant information.

3.2. Formulation of the strategy for the electronic database search

This research was addressed in three phases analysis using the computer-guided surgery technique: the planning, the surgery, and prosthetic phases. The research was based on Medline/PubMed databases from 2007 to 2012 using the phrase "computer-guided implant surgery" for studies written in English, including original researches, clinical reports, technical notes and systematic reviews.

3.3. Inclusion/exclusion criteria

The PubMed search yielded 369 abstracts. Before reading the retrieved abstracts, criteria to be applied for further full text evaluation of a publication were established. To evaluate randomised controlled or comparative studies, the study population had to have at least five patients in each group. Other kind of works, like clinical reports or technical notes, were considered of interest for their scientific contribution. To evaluate implant and prosthesis survival, the patients had to be followed for at least 12 months. However, no specific follow-up period was required to evaluate surgical or prosthetic complications during implant insertion or assess patient-centred outcomes of the surgical intervention and immediate postoperative period. The found reviews were all included in the research. To be selected, the study had to consider at least one of the planning, surgery, or prosthetic phase.

3.4. Results of data extraction

Three assessors read the articles independently and recommended their inclusion or exclusion according to the predetermined criteria. When at least one author considered that a publication met the initial inclusion criteria, the paper was obtained and the full text version read. The initial search identified 369 abstracts, of which 42 studies were included in the review. The publications included: 18 clinical evaluations, 10 technical notes, 8 clinical reports, and 6 reviews (Fig. 1).

All of the authors participated in designing this study, acquiring and interpreting the data, and writing this paper. All authors read and approved the final manuscript.

4. Discussion of the literature review results

4.1. Indications for and purposes of computer-guided surgery

As Table 1 shows, computer-guided surgery is indicated for completely and partially edentulous patients, and some studies included both clinical situations.

Most of the authors stated that computer-guided surgery was indicated for both the maxilla and mandible, although some papers considered only one or the other, and one applied the technique to a reconstructed arch [4]. Computer-guided surgery was used for two reasons: (1) accurate planning for better positioning implants using a tomographic image and (2) fabricating a surgical guide for accurate placement of the implants based on a previously planned position for immediate prosthesis insertion [5].

4.2. Parameter analysis

4.2.1. Virtual planning software

The software used in the studies reviewed included Procera Nobel Guide (Nobel Biocare, Yorba Linda, CA), SIMPLAN (Columbia Scientific, Columbia, MD), SurgiCase (Materialise, Leuven, Belgium), MedScanIIYVirtual Implant (Artma Medical Technologies, Vienna, Austria), image-guided implantology (IGI; Denx Advanced Dental Systems, Moshav Ora, Israel), image-guided oral implant system, Litorim (Leuven Information Technology, Leuven, Belgium), Medicim (Sint-Niklaas, Belgium), Implant3D (med3D, Heidelberg, Germany), 3D SENTCAD software (Media Lab Software, La Spezia, Italy), Stealth Station (Spine 3Ds; Medtronic), EasyGuide Protocol (Keystone-Dental, Burlington, MA), and Exe-Plan software (Brussels, Belgium).

Some software was used more often than the others, and each has advantages and disadvantages. No study compared the different systems. Each system can acquire cone beam images and produce a 3D reconstruction of the maxillofacial bones, making it

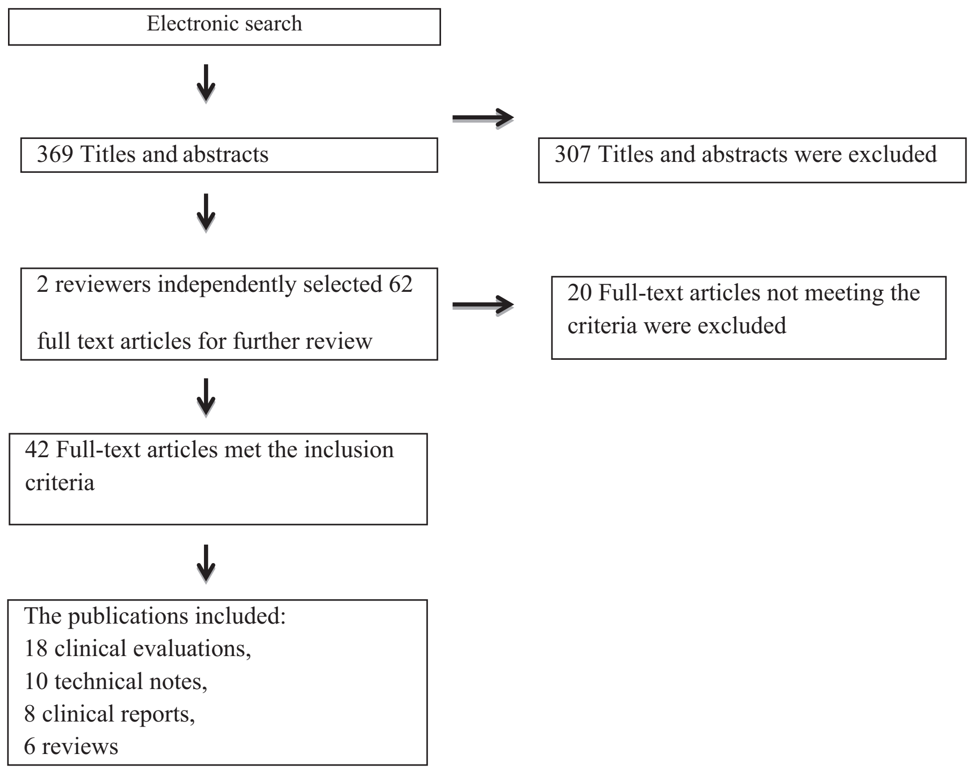

Fig. 1. Results of data extraction. Flow chart of search process and retrieval of publications corresponding to selected inclusion and exclusion criteria.

possible to plan the correct insertion in three dimensions, estimating the depth and relationships with the other teeth to provide better prosthetic and aesthetic results [6]. Other biomechanical considerations are possible, including the horizontal distribution to prevent implant rotation, achieving tripodism, and decreasing the cantilever [7]. The systems can also simulate the implant length and diameter for different bone thicknesses and height.

The final preoperative plan can be sent to a laboratory or certified manufacturing facility to have a stereolithographic surgical template manufactured. Computer-guided template-based implant placement has implant survival rates CSR ranging from 91 to 100%.

Nine clinical studies were evaluated in this review with different survival rates, number of insert implants and follow-up.

Malo et al., reported in a prospective study an implant survival rate of 97.2% in the Maxilla and 100% in the Mandible (92 insert implants, 2 maxillary implants failed), with 13 months of follow-up [17].

Ozan et al. reported in a prospective trial a CSR of 98.3% within 56 inserted implants (one implant failed), and 9 months of follow-up [27].

Wittwer et al. reported in a prospective study a CSR of 97.7% (88 immediate loaded implants, 2 implants failed), after 2 years of follow-up [28].

Yong and Moy reported data, of consecutive treated patients, with a CSR of 91% (78 immediate loaded implants, 8 implants failed), after a mean follow-up period of 26.6 months [19].

Berdougo et al. reported in a controlled study a CSR of 96.30% (test group, 271 flapless inserted implants, 10 implants failed), with a follow-up period up to 4 years [12].

Meloni et al. reported in a retrospective study a CSR of 97.8% (90 immediate loaded implants, 2 failed implants), after 18 months of follow-up [5].

Gillot et al. reported in a clinical study a CSR of 98.1% (211 inserted implants, 4 implants failed), with a follow-up of 12–51 months [34].

Meloni et al. reported in a prospective study a CSR of 95% (56 implants inserted in free-flaps, 3 implants failed), with a follow-up of 12 months [44].

Vasak et al. reported in a prospective study a CSR of 98.8% (163 inserted implants, 2 implants failed), with a follow-up of 12 months [46].

However, the high survival rates in technique-related perioperative complications were observed.

Preclinical and clinical studies have reported a reasonable mean accuracy with relatively high maximum deviations. The observed mean three-dimensional deviation rates between the virtually planned and achieved implant positions varied by around 400 μm (45%) at the implant base and around 540 μm (50%) at the implant tip depending on the CBCT device used [8–10]. The mean vertical deviation was around 370 μm at the implant base and 350 μm at the implant tip, whereas the axis deviation was around 0.81° in the three CBCT devices investigated. Except for the axis deviation and horizontal linear deviations at the implant base, the observed differences among the CBCT devices reached significance.

4.2.2. *Template guided surgery*

The aim of modern surgery is to minimise invasivity. Many authors demonstrated that it is possible to decrease patient discomfort, the length of surgery, aesthetic damage, and tissue trauma [11]. In oral implant placement, minimally invasive surgery often means a flapless procedure. Since it is a blind surgery, some authors limit the procedure to a bone crest at least 7 mm in width [12], while other authors used computer-guided techniques to insert fixtures in patients with thin bone [12,13], post-extraction sockets [11,14], or mandibles reconstructed with free flaps [4].

The introduction of computer-guided surgery permitted the use of flapless surgery with thinner crests, allowing an operative strategy that takes advantage of the localising capabilities of imaging, and performing reported operative procedures with less invasive protocols using a suitable guidance system. The rationale of this approach is based on the precision of these systems [8,9,15,16].

Table 1
Summary of the articles reviewed.

References	Year	Type of study	Edentulism	Arch
de Almeida et al. [25]	2007	Review	Total, partial	Mandible, maxilla
Malo et al. [17]	2007	Clinical evaluation	Total	Mandible, maxilla
Marchack [1]	2007	Technical note	Partial	Mandible, maxilla
Holst et al. [21]	2007	Technical note	Total	Mandible, maxilla
Bedrossian [26]	2007	Technical note	Total, partial	Mandible, maxilla
Ozan et al. [27]	2007	Clinical evaluation	Partial	Mandible, maxilla
Wittwer et al. [28]	2007	Clinical evaluation	Total	Mandible
Azari and Nikzad [29]	2008	Review	Total, partial	Mandible, maxilla
Azari and Nikzad [30]	2008	Review		
Yong and Moy [19]	2008	Clinical evaluation	Partial	Mandible, maxilla
Block and Chandler [31]	2009	Technical note	Total, partial	Mandible, maxilla
Bedard [22]	2009	Technical note	Total, partial	Mandible, maxilla
Dreiseidler et al. [32]	2009	Technical note	Partial	Mandible, maxilla
Sanz and Naert [33]	2009	Review	Total, partial	Mandible, maxilla
Schneider et al. [8]	2009	Review	Total, partial	Mandible, maxilla
Katsoulis et al. [13]	2009	Clinical evaluation	Total	Maxilla
Viegas et al. [23]	2010	Technical note	Partial	In vitro
Berdougo et al. [12]	2010	Clinical evaluation	Total, partial	Mandible, maxilla
Meloni et al. [5]	2010	Clinical evaluation	Total	Maxilla
Gillot et al. [34]	2010	Clinical evaluation	Total	Maxilla
Benech et al. [35]	2011	Clinical report	Total, partial	Mandible, maxilla
Schiroli et al. [36]	2011	Clinical report	Total	Maxilla
Abbound and Orentlicher [37]	2011	Clinical evaluation	Total	In vitro
Yamada et al. [38]	2011	Clinical report	Total	Maxilla
Drago et al. [18]	2011	Clinical evaluation	Total	Mandible, maxilla
Komiyama et al. [15]	2011	Clinical evaluation	Total, partial	Mandible, maxilla
Vasak et al. [16]	2011	Clinical evaluation	Partial	Mandible, maxilla
Abad-Gallegos et al. [39]	2011	Case report	Total, partial	Mandible, maxilla
Margonar et al. [40]	2012	Clinical report	Partial	Maxilla
Papaspyridakos et al. [2]	2012	Clinical report	Total	Mandible, maxilla
Giordano et al. [41]	2012	Clinical evaluation	Total, partial	Mandible, maxilla
De Riu et al. [4]	2012	Technical note	Total	Mandible
Cassetta et al. [42]	2012	Clinical evaluation	Total, partial	Mandible, maxilla
Barnea et al. [43]	2012	Technical note	Total, partial	In vitro
Meloni et al. [44]	2012	Clinical evaluation	Total	Mandible
Yu et al. [10]	2012	Technical note	Partial	In vitro
Schnitman et al. [45]	2012	Case report	Total	Maxilla
Vasak et al. [46]	2012	Clinical evaluation	Partial	Mandible, maxilla
Dreiseidler et al. [9]	2012	Clinical evaluation	Partial	Mandible, maxilla
Kühl et al. [47]	2012	Clinical evaluation	Partial	Cadaver jaw
Puterman et al. [20]	2012	Case report	Total	Mandible, maxilla
D'haese et al. [48]	2012	Review	Total, partial	Mandible, maxilla

Many authors reported that it is possible to make various errors during computer-guided surgery. In an in vitro study, Dreiseidler et al. [9] reported that different CBCT devices could influence the transfer accuracy of computer-assisted implantology with axes deviation of up to 0.6° and linear deviation of around 0.5 mm.

Vasak et al. [16] measured deviation that averaged 0.43 mm (bucco-lingual), 0.46 mm (mesio-distal), and 0.53 mm (depth) at the level of the implant shoulder and slightly greater at the implant apex, averaging 0.7 mm (bucco-lingual), 0.63 mm (mesio-distal) and 0.52 mm (depth). The maximum deviation of 2.02 mm was in the corono-apical direction. Significantly lower deviation was seen for implants in the anterior vs. posterior tooth region ($P < 0.01$), and the deviation was significantly lower in the mandible than in the maxilla ($P = 0.004$) in the mesio-distal direction. Moreover, a significant correlation between deviation and mucosal thickness was found and the surgical procedures involved a learning effect.

For thin mucosa, some authors describe a modification of the technique that consists of using template-guided surgery with a mucoperiosteal flap.

According to Sicilia et al., the importance of using surgical guides in the maxilla is greater for the rehabilitations of edentulous jaw. The technique has two limitations: if the mouth opening is less than 5 cm, the surgical procedure might not be possible [17]; and the precision of the surgery with a guide is influenced by the stabilisation of the template that can be obtained. To obviate the latter problem, the surgical guides are attached to the bone using anchor pins [17] or screws [18].

4.2.3. Prosthetic phase

An immediate-loading protocol maximises the usefulness of the guided surgery techniques. When there is sufficient bone volume and primary stability, it has many benefits, such as short time and maximum patient comfort.

Computer-guided surgery planning not only allows optimal implant positioning according to the prosthetic plan, but also reduces the time the patient is edentulous to almost zero.

In 2003, Gapski et al. [7] described how to obtain clinical success considering four basic sets of factors: surgery, host, system, and occlusion factors. The surgical factors included the primary stability and surgical technique. The host factors included the quality and quantity of trabecular bone, wound healing, and bone turnover activity. The implant factors include design, surface, and length. The prosthetic factors included the quality and quantity of occlusal forces, and prosthesis design. Yong and Moy [19] evaluated cases of guided surgery with immediate insertion of a fixed prosthesis to assess early and late complications. The early surgical complications resulted during bone drilling for implant insertion, while the early prosthetic complications included loss of the prosthesis, problems with phonetics, and lack of bilateral contact. The late surgical complications were related to persistent pain in the implant area and soft tissue defects, whereas the late prosthetic complications were occlusal overload, prosthesis fracture, and unsatisfactory aesthetics.

In 2012, Puterman et al. [20] reported that prosthetic misfit can occur during computer-guided implant placement and the immediate provisionalisation procedure, especially when multiple implants are involved. They reported that the biological adaptation of immediately loaded implants under a static force seems to be responsible for correcting the misfit; however, a combination of framework misfit (static load) and immediately loaded implants (dynamic load) might contribute to the substantially excessive loads that lead to significant bone loss. Therefore, it is recommended that any framework misfit be avoided or corrected in immediate loading situations.

The literature reported a medium deviation of 0.9 mm and 4.5° between the preoperative plan and the implant position obtained after surgery [21–23]. The main causes of this deviation were unstable fixation of the surgical guide, imprecise impressions, and incorrect pouring of the casts [21]. If this deviation is transferred to the immediate loading of a previously fabricated prosthesis, misfit between the components will probably occur and compromise the long-term treatment success [20].

Overall, computer-guided protocols are a reliable treatment modality, but not without complications. Strict adherence to the system protocol is the key to preventing complications.

5. Conclusions

5.1. Common mistakes

Computer-guided surgery consists of a sequence of diagnostic and therapeutic steps, and mistakes can occur at the different stages. The most common mistakes are as follows:

1. Acquisition of tomographic image [9];
2. Fabrication of a surgical guide that do not strictly respects the planned implant position [24];
3. Misfitting of the guide on soft tissues, resulting in displacement during implant installation [5,21,23];
4. Incorrect angulation of the drills during perforation causing lateral deviation [19,24];
5. Reduced mouth opening that displace the surgical instruments during bone perforation [17,19,44];
6. Human errors, such as not follow the implant installation protocol (for example not using the entire length of the drill during perforation) [5,7,19,44].

6. Indications

Based on this literature review, we concluded that:

1. Guided surgery represents an excellent treatment alternative for patients with satisfactory bone quantity for implant insertion and is indicated for complete edentulous arches in the maxilla or mandible [5,16,17,25].
2. Guided surgery is the best treatment choice for patient with limited conditions, like mandible reconstruction with free-flaps after oncological resection [4,44].
3. Procera NobelGuide (Nobel Biocare) was the software used most commonly [25].
4. Although flapless surgery is advantageous for implant positioning, it requires precise indications (sufficient soft-tissues and bone quantity) [14,25,29].
5. For cases with very thin gingiva, guided surgery is helpful for virtual planning, but a flap technique is better [14,25].
6. The stability of the surgical guide must limit the excursion from the planned position (a maximum number of anchor pins is recommended) [44].
7. The order of implant insertion can optimise the stability of the template [4,44].
8. The success of an immediate-loading prosthesis fabricated in advance depends on the accuracy of all of the clinical and laboratorial steps involved in virtual planning [25].
9. In the case of a prosthetic mistake, any framework misfit must be avoided or corrected in immediate loading situations to limit any bone loss [20].
10. The final success is influenced by the maintenance of the prosthesis during the period of bone recovery before delivering the definitive prosthesis [20].

7. Summary

The aim of the present study was to conduct a critical literature review about the treatment concepts of computer-guided surgery in implantology to highlight indication about major advantages and complications of the technique.

The literature review was based on MEDLINE database from 2007 to 2012 using the key words “computer-guided implant surgery” for studies written in English. For inclusion, publications had to meet pre-established criteria. Three reviewers independently selected 42 full text articles. The publications included: 18 clinical evaluation, 10 technical notes, 8 clinical report, and 6 reviews.

The scientific evidence available suggests that guided placement has at least as good implant survival as conventional protocols. However several unexpected procedure-linked adverse events during guided implant placement indicate that the clinical demands on the surgeon were no less than those during conventional placement.

Computer-guided surgery consists of a sequence of diagnostic and therapeutic steps, and mistakes can occur at the different stages. The most common mistakes are as follows:

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